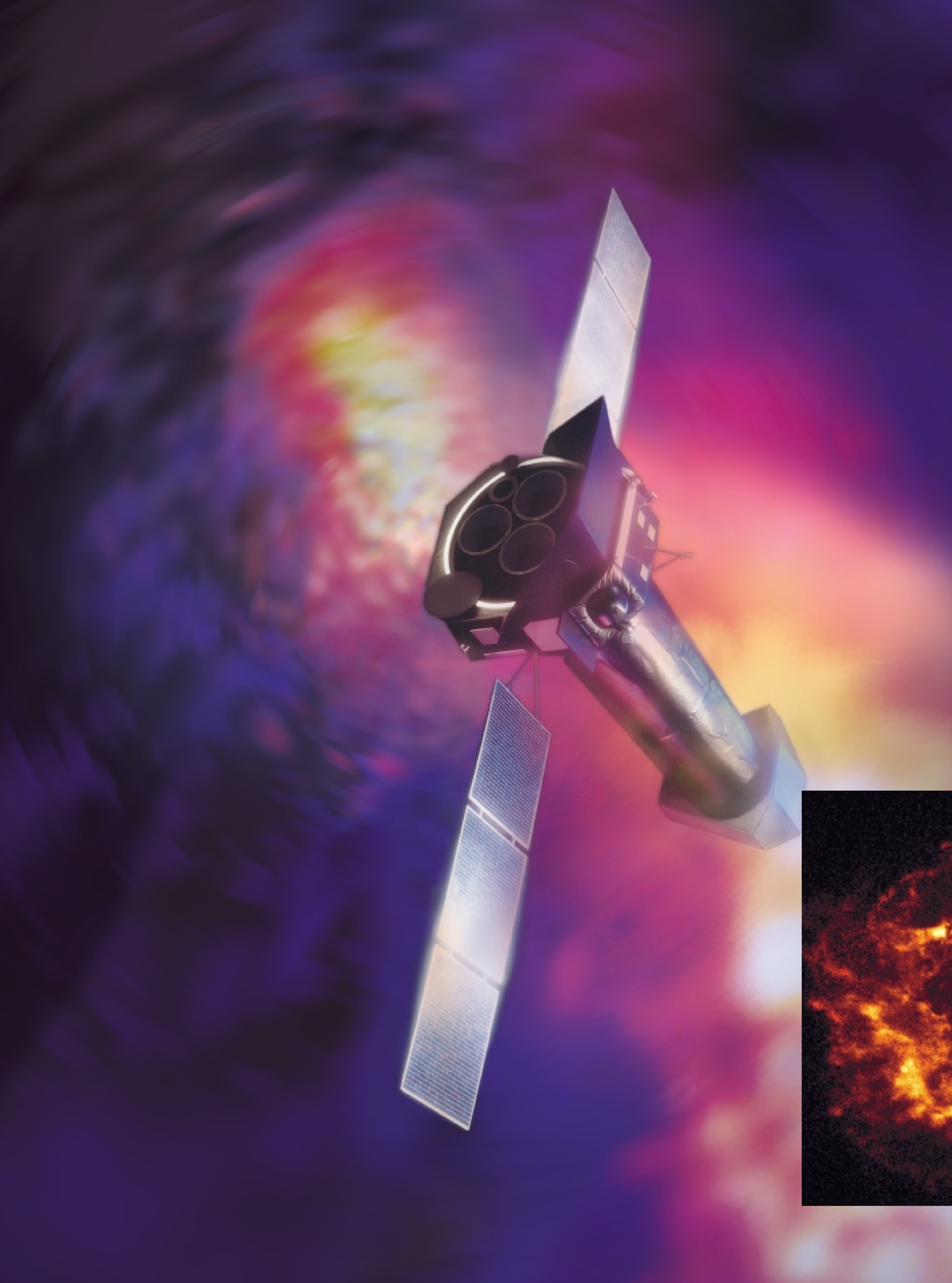

XMM: Advancing Science with the High-Throughput X-Ray Spectroscopy Mission

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The X-Ray Multi-Mirror Mission (XMM) is an X-ray astrophysics observatory scheduled for launch in December 1999. With a projected lifetime of 10 years, it will enable astronomers to conduct sensitive spectroscopic observations of a wide variety of cosmic sources.

X-ray astronomy primarily involves the study of plasmas having temperatures in the range of 10^6 to 10^8 K. Such plasmas radiate the bulk of their energy at X-ray wavelengths between 100 eV and 15 keV (0.8 - 120 Å). Apart from X-ray continuum emission, produced through such processes as thermal Bremsstrahlung, a significant fraction of the total emissivity may arise from line emission. At these high temperatures, cosmically abundant elements such as hydrogen and helium are stripped of all of their electrons. Only heavier elements can, depending on the temperature, retain their K- or L-shell electrons. The study of transitions from these elements, which are primarily in a hydrogenic or helium-like state, represents an important diagnostic tool for achieving an understanding of the physics of cosmic X-ray sources.

As the mechanisms and the conditions underlying the generation of visible light and X-rays are completely different, comparing the two provides useful complementary information. A comparison of the visible and X-ray emissions for the young supernova remnant Cas A is shown in Figure 1. These images clearly illustrate that there is a lot to be learnt about the highly energetic processes underlying the emission of X-rays from exploding stars, accreting black holes, etc.

XMM is specifically designed to investigate in detail the spectra of cosmic X-ray sources down to a limiting flux of 10^{-15} ergs/cm^2/s. It will be able to detect X-ray sources down to a few times 10^{-16} ergs/cm^2/s. With XMM, it will be possible to routinely perform such measurements, whereas on previous missions this was either impossible or required an excessive amount of observing time.

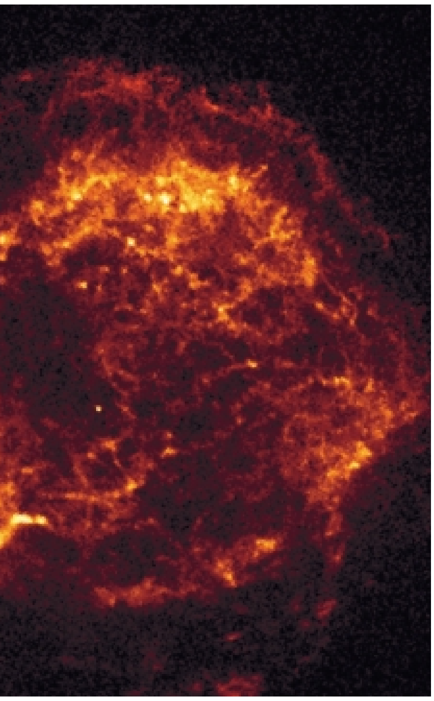

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Figure 1a. The supernova remnant Cas A, as seen in X-rays. The emission is caused by stellar ejecta, which have been heated to several million degrees by the passage of the blast wave associated with the explosion of the progenitor star ~350 years ago (courtesy of NASA/CXC/SAO)

Figure 1b. The supernova remnant Cas A, as seen in visible light. Although the global structure, as shown in Figure 1a can still be identified, the actual material and conditions of the emitting medium are quite different (courtesy of MDM)

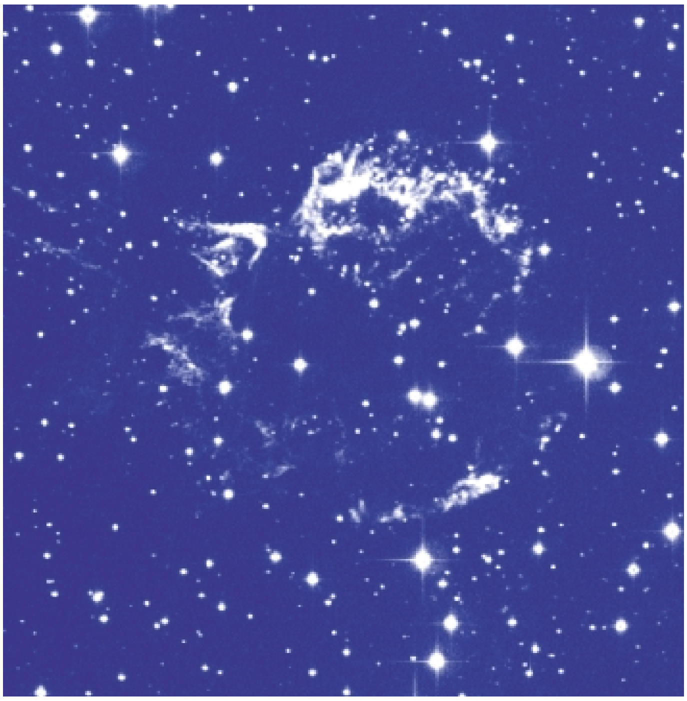

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Figure 2. The XMM Structural Thermal Model (STM) in the ESTEC clean room

The principal characteristics of XMM (Fig. 2) can be summarised as follows:

- effective collection area 4500 cm^2 at 1 keV (12.4 Å) and 1000 cm^2 at 10 keV (1.24 Å)
- almost constant angular resolution across the full waveband of ~ 15 arcsec HEW (Half-Energy Width)
- X-ray field of view ~30 arcmin
- capability of performing sensitive medium-resolution spectroscopy with resolving powers between 100 and 700 over the wavelength band 5 – 35 Å (350 – 2500 eV)
- broadband imaging spectroscopy from 100 eV to 15 keV (0.8 – 120 Å)
- simultaneous sensitive coverage of the wavelength band 1600 – 6000 Å (~17 arcmin field of view) through a dedicated optical monitor, co-aligned with the X-ray telescopes
- continuous coverage of a source for up to 42 h (except for a small gap around apogee).

A suite of complementary instruments on board the XMM mission brings about these characteristics.

The European Photon Imaging Camera (EPIC) instrument provides an X-ray imaging camera for each of the three telescope modules of XMM. The detectors are based on cooled Charge-Coupled Devices (2 MOS-CCD cameras, 1 p-n CCD camera), operating in a photon-counting mode to provide simultaneous imaging and non-dispersive spectroscopy (spectral resolving power ~7 at 0.2 keV to ~70 at 15 keV) for every field that XMM observes. These powerful diagnostics will have a significant impact on every branch of X-ray astrophysics. An example of the very high performance of these instruments is shown in Figure 3.

The mission's aim of providing a medium-resolution spectroscopic capability is achieved by means of two Reflection Grating Spectrometers (RGSs). The grating arrays are placed directly behind two of the three Mirror Modules, in front of the EPIC MOS cameras, and each intercepts about 50% of the converging beams. Position- and energy-sensitive readout at the spectroscopic (secondary) focus is performed by strip arrays of nine MOS CCDs each. The energy resolution of these CCDs is used to separate the overlapping diffraction orders –1 and –2, and to reject background arising from diffuse X-rays as well as from particle radiation or internal detector effects (Fig. 4).

These X-ray instruments are placed behind one of the major achievements of XMM, the X-ray mirrors. Having set out to achieve a

performance of 30 arcsec Half-Energy Width (HEW) at 2 keV, the actual achieved performance is a factor of 2 better (Table 1).

The Optical Monitor (OM) enables XMM to provide simultaneous coverage of the telescope field in the waveband 1700 to 6000 Å. The 30 cm Cassegrain telescope will cover a 17 by 17 arcmin^2 field with an angular resolution of ~1 arcsec through the use of photon-counting detectors. This instrument is also equipped with a standard set of U, B and V filters, as well as specific UV-wavelength band filters and two grisms for low-resolution dispersive spectroscopy over the full wavelength band.

The XMM orbit will be a 40 deg, southern-inclination orbit which allows for > 95 % visibility of the sky over the first two years of the mission's lifetime.

The XMM Science Operations Centre (SOC) is located at ESA's Vilspa (Villafranca del Castillo) facility, near Madrid (E), and supports the scientific part of the XMM operations:

– Issuing Announcements of Opportunity (AOs) and coordinating the peer-review process to arrive at the scientifically optimum XMM observing programme.
– Writing the XMM User's Handbook, which is the guide to be used by guest observers in preparing their proposals.

*Table 1. XMM Mirror Module measured X-ray imaging performance**

In arcsec:	FM1	FM2	FM3	FM4
FWHM @ 1.5 keV	8.4	6.6	6.0	4.5
FWHM @ 8.0 keV	7.7	6.6	5.1	4.2
HEW @ 1.5 keV	15.2	15.1	13.6	12.8
HEW @ 8.0 keV	14.4	14.8	12.5	12.2
W90 @ 1.5 keV	56.8	57.2	48.1	58.0
W90 @ 8.0 keV	161.0	182.0	153.0	130.0

* The actual Mirror Modules mounted on XMM for flight are FM2, 3 and 4.

– Performing the mission planning.
– Distributing the observation files to the observers.
– Performing the calibration of the instruments.
– Defining and writing the software required to scientifically simulate the performance of the full XMM observatory (SciSIM). This component is actively used in determining and predicting the calibration of the instruments on-board the XMM observatory. Examples of the use and capabilities of the SciSIM are shown in Figures 3 and 4.

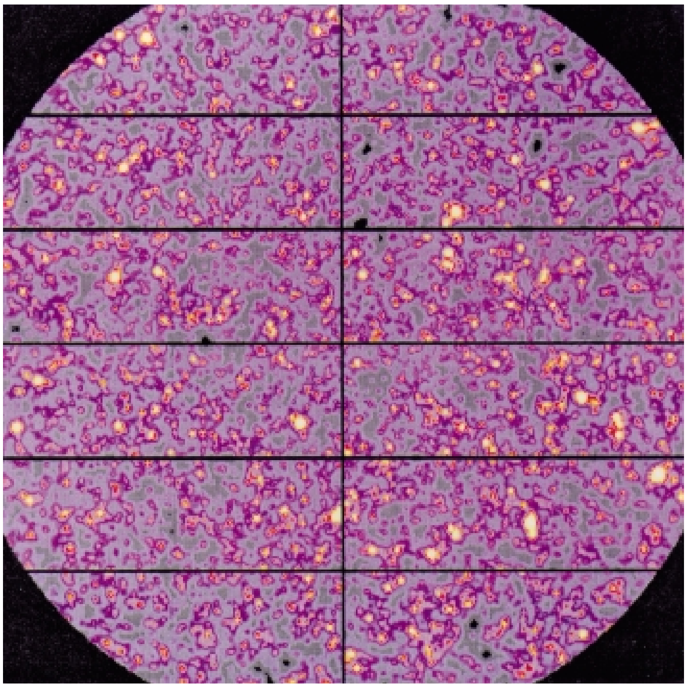

Figure 3. A simulated EPIC p-n camera deep-field exposure. A 200 000 sec deep-field exposure has been simulated using the source number versus source strength (log N - log S) relationship extrapolated down to 10^{-16} erg/cm^2/s. The full 30 arcmin field of view is shown (courtesy of D. Lumb, ESTEC)

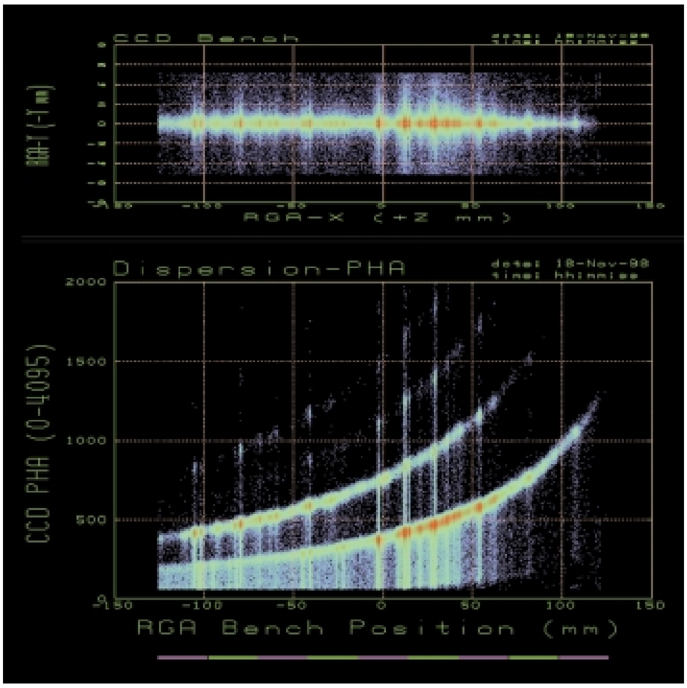

Figure 4. Simulation of an XMM RGS observation of Capella. The top panel shows the image in the spectroscopic focus with the dispersion direction along the abscissa. The lower panel shows the same information on the abscissa, but here the ordinate uses the CCD energy information, thus illustrating the mechanism separating the grating orders. All the bright features are resolved spectral lines in the spectrum of Capella

– Defining and writing the software required to analyse XMM data (SAS). This is a collaborative effort with the AO-selected, Survey Science Consortium (SSC).
– Ensuring the public availability of the standard analysis results, as made available by the SSC.

The first XMM Announcement of Opportunity (AO-1) attracted the attention of an astonishing number (~2000) of professional astronomers worldwide, which approximately amounts to 25% of the World's astronomical community. The number of proposals received was seven times higher than the volume that could be accommodated.

One of the major areas of development has been the XMM Scientific Analysis System (SAS). This comprises both the interactive analysis and the pipeline software used by the SSC to routinely process all XMM data. In this area, the SOC has developed a set of software layers known as the Data Access Layer (DAL) and Calibration Access Layer (CAL), which largely simplify the (re-)use of XMM software by other analysis systems and also allow simpler interfaces between the SAS development teams at the different sites. All of these features are present in the third release (internal to ESA and SSC) of the full SAS software package, which also is available for limited external testing.

Another part of the work performed by the SOC was the description of the calibration of the XMM instruments. This is especially difficult for traditional items like the Response Matrix File (RMF). For detailed analysis of data of the quality and spectral resolution to be generated by XMM, it is no longer sufficient to store a (limited) set of RMFs that could be made available to the observers. A full set of RMFs would require so much disk storage that it would be prohibitive for the XMM observers to use them. Instead, it is generally recognised that software will have to be written which generates these response matrices instantly, taking into account all details of the dataset and instrument being analysed. By using prototype versions of this software, this approach has proven to be a viable and promising option.

The SOC has developed, in coordination with the XMM Science Working Team (SWT), a coherent programme for the XMM in-orbit calibration and performance verification phase. This phase is going to take three months to execute, rather than the two months originally proposed. The extra time is required to compensate for some of the instrument calibration, which could not be performed on the ground due to time pressures.

In its preparation of operational activities, the SOC has run through a number of science cases and compared XMM to other missions. An important feature of XMM is how it complements the NASA Chandra mission. The main features of XMM (compared to Chandra) are:
– Point spread function nearly independent of energy.
– Point spread function nearly constant over full FOV (30 arcmin).
– Effective area: at 2 keV, 5 times Chandra; at 10 keV, ~50 times Chandra.
– All instruments operate simultaneously, which gives XMM a large multiplexing advantage over many previous and contemporaneous missions.
– Optical Monitor available, which will allow for simultaneous optical coverage of most XMM observed fields without having to revert to logistically complex, ground/space-based co-ordinated observations.
– No degradation of the RGS spectral resolution for slightly extended (~10 arcsec) sources. This is important as it will allow for unprecedented high-spectral-resolution studies of slightly extended objects.

The science best performed with Chandra will focus on the use of its high spatial resolution and very high-resolution spectroscopy of bright X-ray sources, whereas XMM will, inter alia, excel in the study of faint extended high-temperature plasmas, where its capabilities are unrivalled and unique.

In summary, XMM will bring the opportunity to greatly expand the number of known X-ray sources and extend our knowledge on the already known population of X-ray sources.